764
cy 2

TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 764

FLIGHT INVESTIGATION OF CONTROL-STICK VIBRATION OF THE YG-1B AUTOGIRO

By F. J. Bailey, Jr.
Langley Memorial Aeronautical Laboratory

Washington
June 1940

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE NO. 764

FLIGHT INVESTIGATION OF CONTROL-STICK VIBRATION OF THE YG-1B AUTOGIRO

By F. J. Bailey, Jr.

SUMMARY

As a preliminary step in an investigation of control-stick vibration in direct-control autogiros, the periodic variations in the moments transmitted through the control system of a YG-1B autogiro were recorded in flight. The results of the measurements are presented in the form of coefficients of Fourier series expressing the varying part of the lateral and the longitudinal moments acting between rotor and fuselage at the control trunnions.

The most important component of the variation in stick force was found to have a frequency of three times the rotor speed and an amplitude that rose from negligible values at tip-speed ratios below 0.20 to ±5.2 pounds longitudinally and ±3.2 pounds laterally at tip-speed ratios of 0.35. Variations in stick force at all other frequencies were small in comparison with those at three times the rotor speed.

INTRODUCTION

Conventional three-blade direct-control autogiros of the tilting-hub type are generally regarded as unsuitable for extended cross-country flights, largely because of the severe vibration of the control stick that appears at air speeds above 80 miles per hour. The importance of the problem of stick vibration has been recognized by designers and several solutions have been proposed. Because the relative importance of the various elements of the control arrangement, as regards their contribution to stick vibration, has never been established, the tendency has been to devise an arrangement of the hub and the blades that will exclude all possibility of disturbing forces capable of causing stick vibration. Consequently, all the solu-

tions proposed have involved radical departures from conventional arrangements and their development has been slow. As yet, no entirely satisfactory solution has evolved.

The fundamental cause of stick vibration is a periodic variation in the moment acting between the rotor and the fuselage at the lateral-control and the longitudinal-control trunnions. From time to time, attempts have been made to express theoretically the variation in moment and to determine the modifications required to eliminate the disturbance. Such attempts have shown some promise but have always been handicapped by lack of specific experimental data against which the calculations could be checked to establish the validity of the assumptions on which they are necessarily based.

To obtain the desired experimental data, the National Advisory Committee for Aeronautics has been conducting a program of stick-vibration tests on the YG-1B autogiro lent the Committee by the Army Air Corps. During these tests, which have been completed, the varying loads in the control system were recorded and the variation of the trunnion moments with rotor azimuth position was established. The results of the tests are reported herein.

APPARATUS AND TESTS

The YG-1B autogiro (fig. 1) used for the tests is a two-place 225-horsepower direct-control machine of the tilting-hub type, having a 40-foot-diameter three-blade rotor. As flown during the tests, with pilot only, the weight was 2,130 pounds.

The rotor blades, which had a 12-inch chord, were of the Göttingen 606 airfoil section. Over the outboard portion of the blades, between 72 and 93 percent of the radius, the chord was extended 1 inch by a trailing-edge tab. The tab was reflexed approximately 10° to counteract the unstable center-of-pressure travel of the Göttingen 606 section.

The arrangement of the rotor hub is shown in figure 2. The axes of the lateral and the longitudinal trunnions, about which the hub is tilted for control, intersect in a point 7/16 inch to the left and 1-5/8 inches ahead of the rotor axis and 2-3/4 inches below the plane

of the flapping hinges. The mechanical advantage between stick and hub, determined by measuring the angular motion of the two with the system in the positions covered by the flights, is 5.27 laterally and 3.86 longitudinally. The stick length is approximately 1.9 feet; hence a variation of 1 pound in the lateral or the longitudinal stick force corresponds to a variation of 10 foot-pounds in the lateral trunnion moment and 7.3 foot-pounds in the longitudinal trunnion moment, respectively.

The variation in the loads in the control system was recorded by an N.A.C.A. stick-type control-force recorder. This instrument was calibrated to give the lateral and the longitudinal moments about the stick pivots, applied to the base of the stick by the control system. Multiplication of the stick moments by the lateral and the longitudinal mechanical advantages of the system gave the varying moments acting between fuselage and rotor at the trunnion axes. Trunnion moments are considered positive when the air forces tend to tilt the rotor to the right and to the rear.

In over-all dimensions, the control-force recording stick was a reproduction of the original control stick. It was designed to record, on a film, the lateral and the longitudinal deformations of a flexible, elastic section located near its lower end.

In order to record properly the periodic loads of the control system with the apparatus just described, it was necessary to minimize the motion of the stick relative to the fuselage. For this reason, the stick was held as tightly as possible while the records were being taken. In addition, the inertia of the upper part of the stick, already larger than that of the normal stick because of the heavier material used in its construction, was augmented by wrapping a 5-pound bag of lead shot around the handgrip. Subsequent comparison of the amplitudes of the moment variations recorded with the stick free without the lead shot on the handgrip and with the stick held in the manner just described indicated that no further increase in the recorded amplitude would have been obtained by clamping the stick.

The timing circuit of the control-force recorder was connected to a contacting device on the rotor hub, designed to produce a break in the timing line once per revolution of the rotor. Hence, the relation between the varying

loads in the control system and the azimuth position of the rotor could be established from the records.

Rotor speed, air speed, and engine speed were noted by the pilot from observations of the regular flight instruments. The accuracy of the pilot's rotor tachometer had, however, been checked against a revolution-recording device in previous flights.

Records were taken in both gliding and level flight over a range of air speeds from 40 to 105 miles per hour. The altitudes of the different runs varied from 2,000 to 3,500 feet.

In every case the test procedure was the same; the autogiro was flown steadily, the mean value of the stick force was made approximately zero by means of the "bungee," and the stick was held tightly while a 1- or 2-second record was taken.

The bungee consists essentially of a steel spring acting between the hub and the fuselage, restraining the tilting of the hub about the trunnions. Changes in the bungee setting change the tension in the spring and therefore change the mean stick force required for trim. The bungee has no effect on the periodically varying part of the stick force, as long as the stick is held fixed.

RESULTS

Reproductions of several typical records are shown in figure 3. The starts of the short breaks in the timing line correspond to an azimuth of 157° for blade 1, one complete revolution of the rotor taking place between successive breaks. An upward deflection of the records of longitudinal and lateral force indicates that the pilot is exerting force forward and to the right on the stick. The relative unimportance of any first harmonic variation in the trunnion moments is at once apparent from the records.

Analysis of the records to determine the actual variation of trunnion moment is complicated by the fact that the response, of an instrument of the type used, to a periodically varying moment acting on the base of the stick depends not only on the magnitude of the change in moment but also on the damping present in the instrument and on

the ratio of the frequency of the moment variation to the natural frequency of the instrument. In the present case, the instrument had very little damping and had a natural frequency of 31 cycles per second. Theory indicates that its response to frequencies below 31 should be exactly in phase with the impressed-moment variation. The amplitude of response to a variation occurring at a frequency of n cycles per second should be $1\Big/\sqrt{\left(1 - \frac{n^2}{31^2}\right)^2}$ times as great as to the same variation occurring statically. (See reference 1.) In the use of this expression, each component must be separately considered. In order to determine the actual periodic variation in trunnion moment, the record was broken down into its component frequencies by harmonic analysis and the amplitude of each frequency was modified by the appropriate factor.

The first step in the analysis of the records was to determine the azimuth position of the rotor as a function of the distance along the film. The azimuth position was ordinarily determined on the assumption that the film speed and the rotor speed were constant between the revolution marks. In a few cases, where this assumption was obviously in error, a curve of film speed against distance along the record was established by measuring the distance between peaks on the vibration records and assuming that these peaks were exactly 120° apart. The curve established in this way was, of course, confirmed by the average film speed over each revolution as obtained from the revolution marks.

After the relation between rotor azimuth and distance along the film had been established, the ordinates of the record lines were read at points corresponding to every 10° in azimuth of blade 1 from 0° to 360° for three consecutive revolutions.

In general, the moment variation given by the records could be satisfactorily approximated by a single cycle repeated three times per revolution of the rotor and involving only third, sixth, and ninth harmonics of the rotor speed. Accordingly, the coefficients of the Fourier series expressing this cycle were determined by harmonic analysis from averages of the ordinates of the nine successive cycles. Figures 4 to 7 illustrate the agreement of the series with the experimental values from which it was derived. The experimental points on figures 6 and 7 indicate the degree to which successive cycles in the same revolution differed from one another. No significance

should be attached to the mean values of the moments shown on the figures. The departures of the mean value from zero merely indicate failure to trim out average stick forces with the bungee.

As previously mentioned, the recorded moments shown in figures 4 to 7 are not the actual moments in the control system because the response of the recording instrument to a periodic variation in moment depends on the frequency, as well as on the magnitude, of the variation. Only after each of the coefficients of the Fourier series was modified by the proper factor was the actual variation in impressed moment obtained. An idea as to the effect of this modification can be obtained from figures 8 and 9, where both the recorded and the actual moments are compared. In general, the amplitude of the third harmonic was reduced about 12 percent and that of the sixth harmonic, about 70 percent. The small ninth harmonic became negligible.

The varying part of the actual longitudinal moment at the trunnions was therefore found to be expressible, in terms of the azimuth angle ψ, by the four-term Fourier series.

$$\Delta M = A_3 \cos 3\psi + B_3 \sin 3\psi + A_6 \cos 6\psi + B_6 \sin 6\psi$$

The values of the coefficients A_3, B_3, A_6, and B_6, obtained in the manner just described, are presented as functions of the tip-speed ratio μ in figure 10.

Coefficients of a similar series expressing the varying part of the lateral moment at the trunnions are given in figure 11.

The lateral and the longitudinal coefficients are tabulated, along with the corresponding values of tip-speed ratio, rotor speed, and engine speed, in table I.

Except for the last run, at a tip-speed ratio of 0.356, the coefficients shown in figures 10 and 11 and in table I are based on records obtained in glides. A number of additional records of the longitudinal moment were obtained in level flight. The results are omitted because analysis of the records was carried out only far enough to establish the fact that coefficients obtained in level flight would not differ appreciably from those for glides.

DISCUSSION

Accidental errors are indicated by the dispersion of the points in figures 10 and 11. A considerable part of this dispersion, particularly in the case of the sixth harmonic, is believed to be traceable to errors in the determination of rotor azimuth, resulting from variations in the film speed. The irregularities in film speed are inherent in the control-force recorder and cannot be eliminated without a radical change in the design of the instrument. Their effect, however, can be minimized in any future tests by providing for more frequent breaks in the timing line so that the exact azimuth position of the rotor will be known several times during each revolution.

Another possible source of the accidental errors in the coefficients lies in the use of a harmonic analysis based on only 12 points during each cycle. In the presence of the superimposed high-frequency engine vibration, the 12-point analysis would hardly be adequate if only a single cycle were to be analyzed. No connection exists between the engine and the rotor, however, and each successive recorded cycle of the rotor vibration will ordinarily be differently modified by engine vibration. Only when the engine speed or the frequency of firing of the cylinders is an integral multiple of the third harmonic of the rotor speed will successive cycles be identically affected. Hence, coefficients determined from an average curve for nine successive cycles should be relatively free from errors due to the use of the 12-point harmonic analysis.

The amplitude of the periodic third-harmonic variation in trunnion moment is given by the expression $\sqrt{A_3^2 + B_3^2}$. Application of this expression to the data given in figures 10 and 11 shows that, at a tip-speed ratio of 0.35, the periodic variation in trunnion moment was ±38 foot-pounds longitudinally and ±32 foot-pounds laterally. The corresponding variation in stick force was ±5.2 pounds longitudinally and ±3.2 pounds laterally. The vibration under these conditions was regarded by the pilot as severe.

As the tip-speed ratio is reduced, the vibration rapidly decreases. At a tip-speed ratio of 0.20, the lon-

gitudinal variation in stick force was ±1.2 pounds and the lateral was ±0.2 pound. Under these conditions, the pilot found the vibration insignificant.

In the interpretation of the results of the tests, it is important to remember that the coefficients given in figures 10 and 11 do not necessarily express the periodic moments of the disturbing forces tending to tilt the rotor about the trunnions. With the stick held motionless relative to the fuselage, the autogiro constitutes an elastic system involving two masses, one the fuselage and the other the rotor, restrained from rotating relative to one another at the trunnions by an elastic member, the control system. How closely the periodic moment in the connecting member approximates the periodic disturbing moment depends on the ratio of the frequency of the disturbing moment to the natural frequency of the elastic system and on the amount of damping present. It is the periodic moment in the connecting member, however, that determines the periodic variation of the stick force and it is this periodic moment that is expressed by the coefficients.

When the stick is free, the same situation exists except that the elastic connecting member is the bungee spring instead of the control system. In this case, the entire control system moves with the hub, increasing the effective inertia of the rotor.

The determination of the actual disturbing moments applied to the rotor by the air forces would, of course, be desirable for comparison with theoretical calculations of the air-force variations. Before this determination can be made, however, the natural frequency and the damping of the elastic system composed of the rotor, the fuselage, and the control system will have to be determined. As yet no satisfactory method of determining this natural frequency and damping has been found.

CONCLUSIONS

1. The most important component of periodic variation in the stick force of the YG-1B autogiro has a frequency of three times the rotor speed; variations at all other frequencies are unimportant in comparison with that at three times the rotor speed.

2. The amplitude of the third-harmonic variation in stick force was ±5.2 pounds longitudinally and ±3.2 pounds laterally at a tip-speed ratio of 0.35.

3. The periodic variations in stick force were negligible at tip-speed ratios below 0.20.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., April 4, 1940.

REFERENCE

1. Timoshenko, S.: Vibration Problems in Engineering. D. Van Nostrand Co., Inc., New York, N. Y., 1928, pp. 26-32.

Table I

SUMMARY OF STICK-VIBRATION DATA

Tip-speed ratio, μ	Rotor speed (rpm)	Engine speed (rpm)	Coefficients of longitudinal moment (ft-lb)				Coefficients of lateral moment (ft-lb)			
			A_3	B_3	A_6	B_6	A_3	B_3	A_6	B_6
0.218	199	650	3.6	11.3	1.5	1.2	-2.1	0.2	-0.1	-0.2
.232	202	700	4.3	8.0	0	2.0	-5.7	-2.1	0	.3
.251	203	760	7.0	17.8	.5	2.8	-4.4	-.9	-.2	.6
.265	205	800	6.0	17.6	-1.5	5.9	-8.8	-3.5	-.8	1.0
.284	206	900	14.2	20.5	2.3	3.3	-10.8	-1.2	-1.4	.7
.292	210	950	7.2	21.8	-3.0	7.3	-20.5	-2.1	-1.6	-3.4
.313	212	1,000	8.7	23.4	-2.0	5.7	-21.0	-2.6	-2.1	-3.2
.325	210	1,100	12.5	27.3	.1	6.6	-25.0	1.5	-4.5	-1.3
.356	212	2,000	20.1	37.2	3.1	7.4	-32.9	5.2	-4.1	-.1

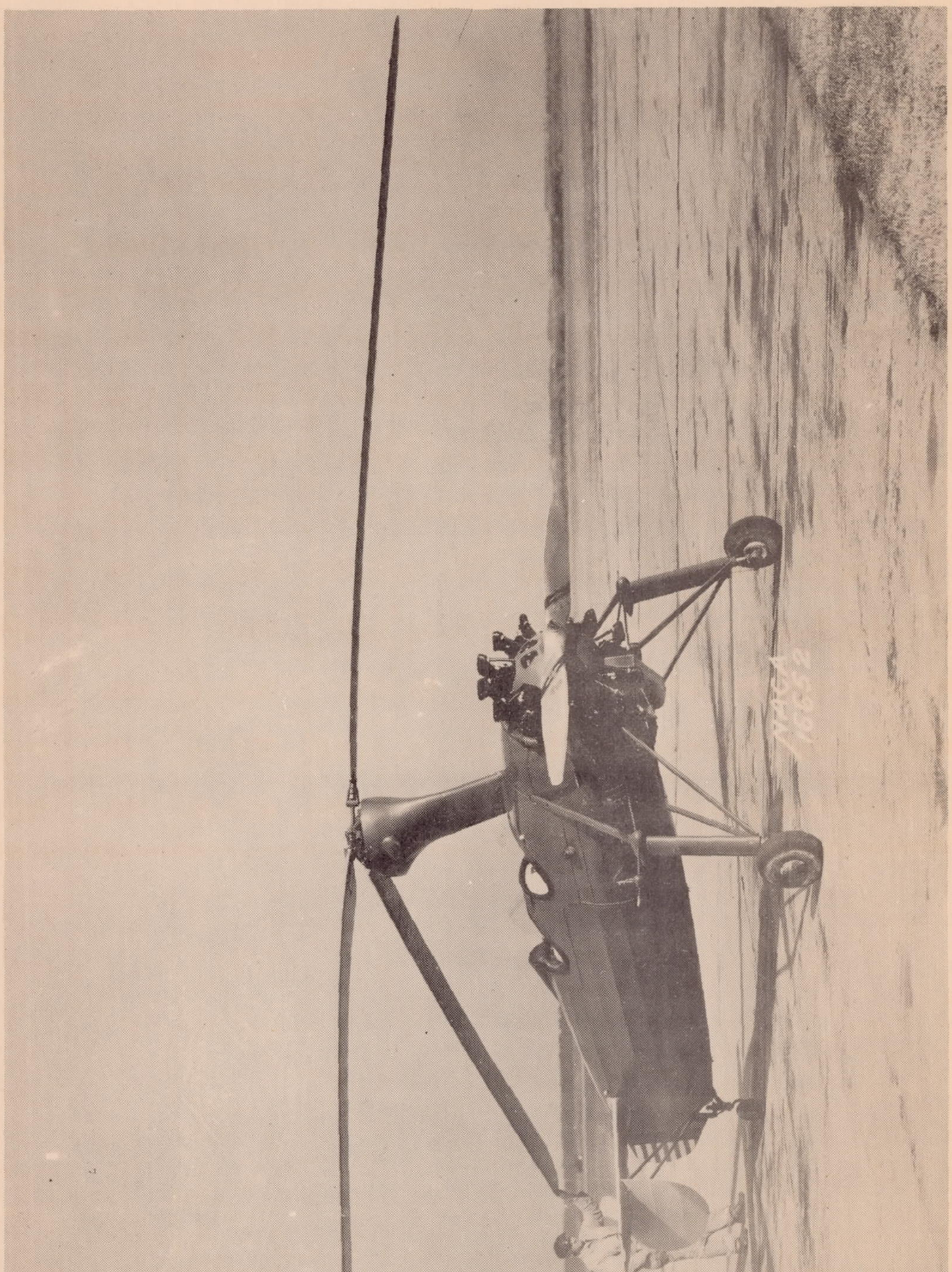


Figure 1.- The YG-1B autogiro.

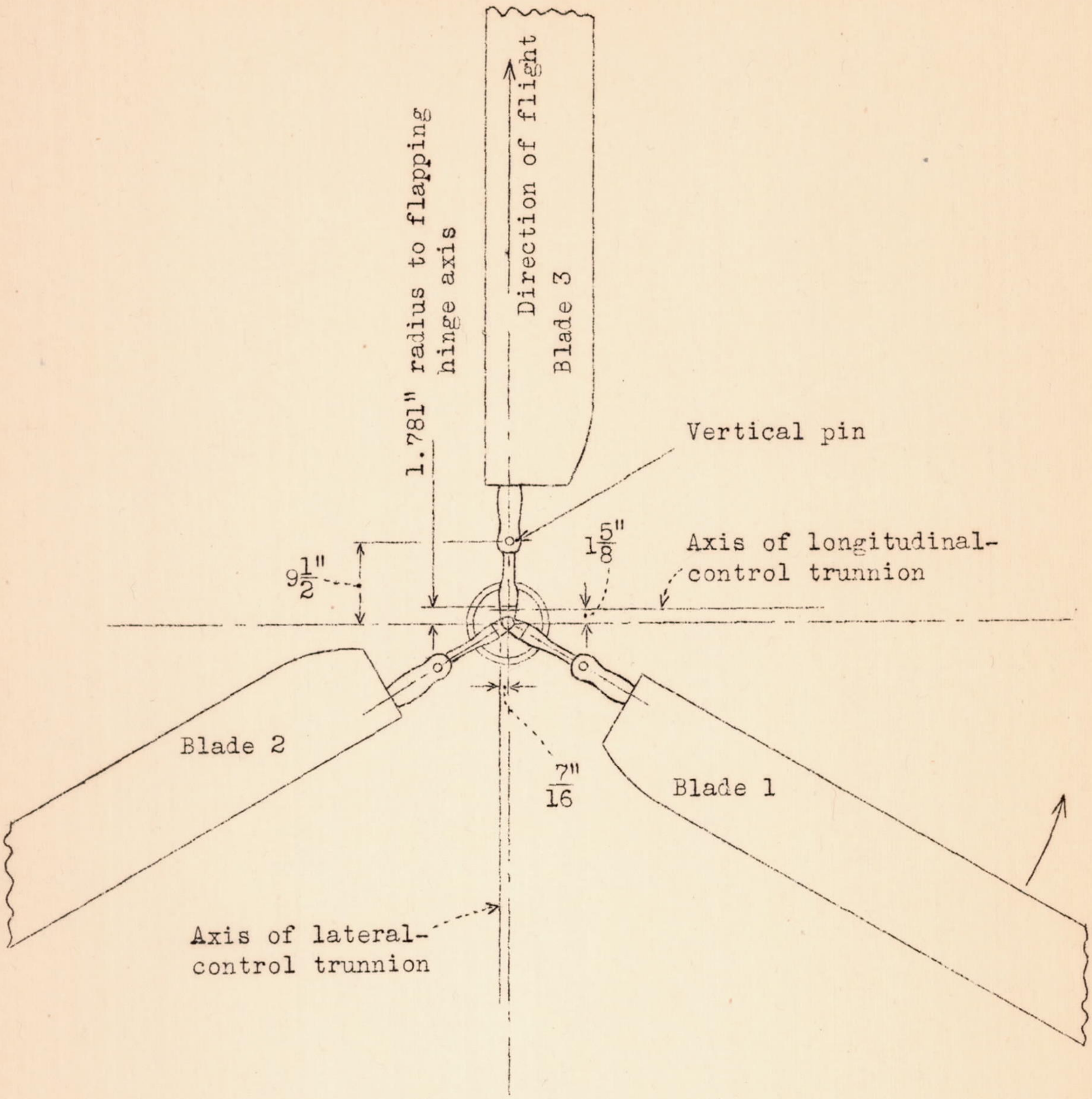
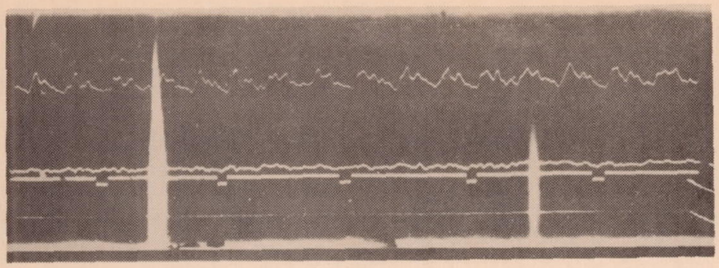
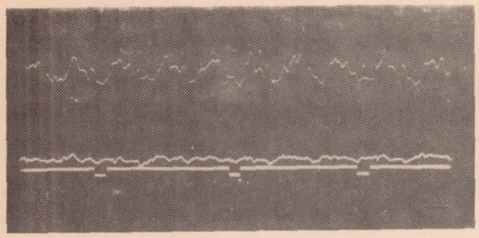


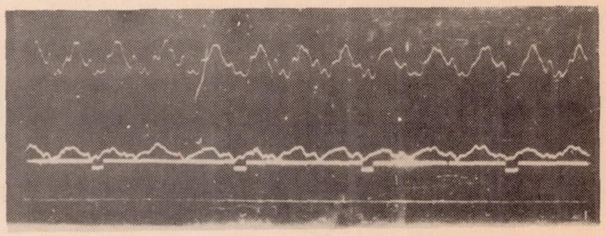
Figure 2.- Sketch of rotor hub arrangement of YG-1B autogiro. Trunnion axes are 2-3/4 inches below the plane determined by the flapping hinge axes.



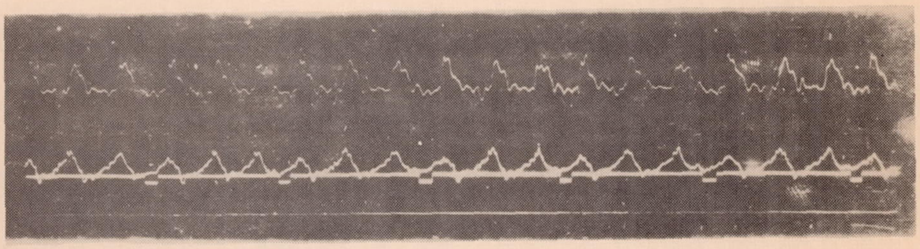
Tip speed ratio, $\mu = 0.218$. Rotor speed = 199 rpm



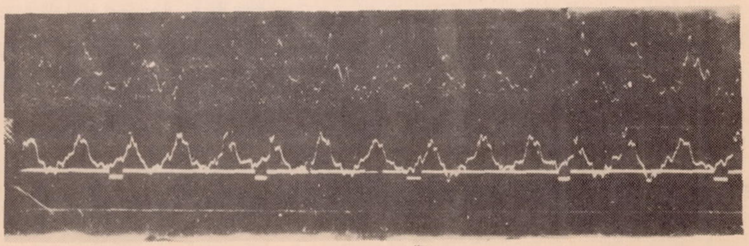
$\mu = 0.251$, 203 rpm



$\mu = 0.284$, 206 rpm



$\mu = 0.313$, 212 rpm



$\mu = 0.356$, 212 rpm

Figure 3.- Typical records of periodic variation of control force. YG-1B autogiro.

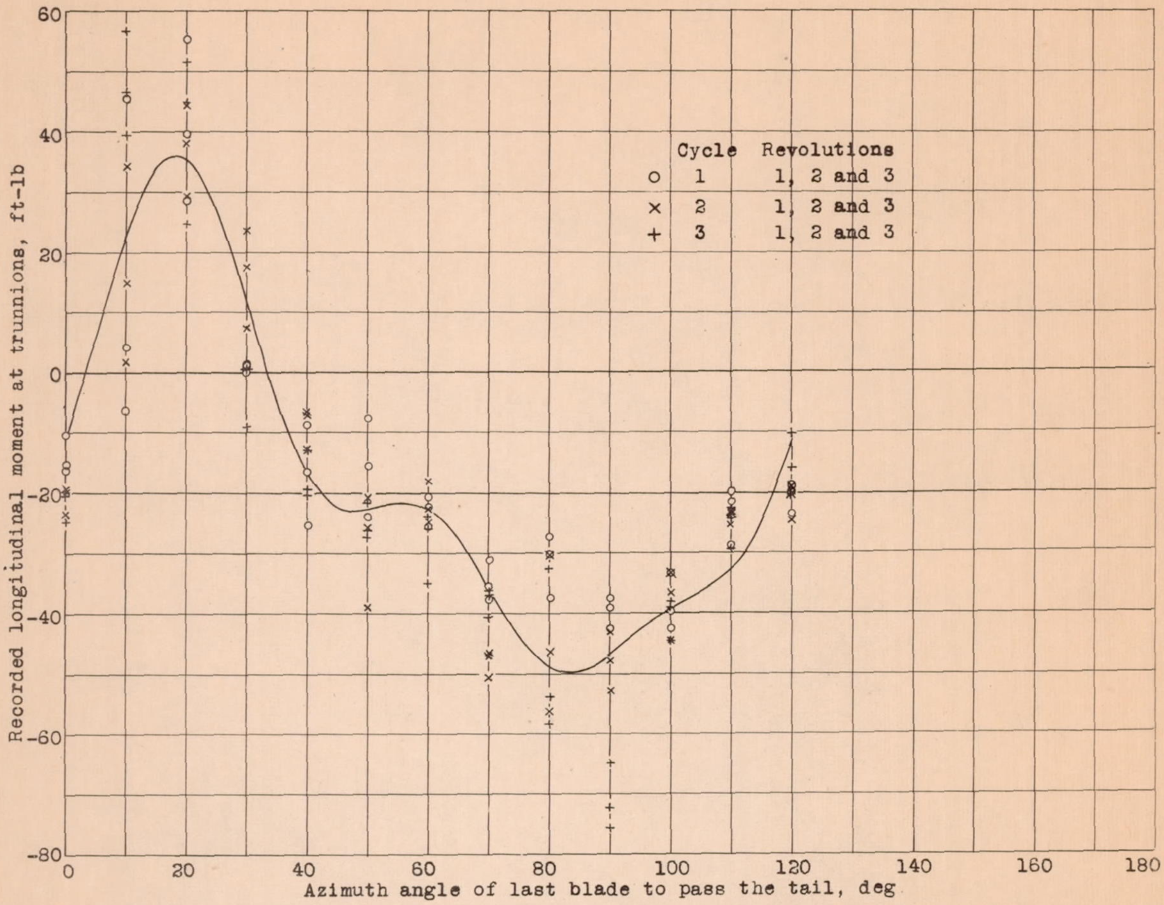


Figure 4.- Variation of recorded longitudinal moment at the trunnions with azimuth angle of the last rotor blade to pass over the tail. $\mu = 0.325$. YG - 1B autogiro.

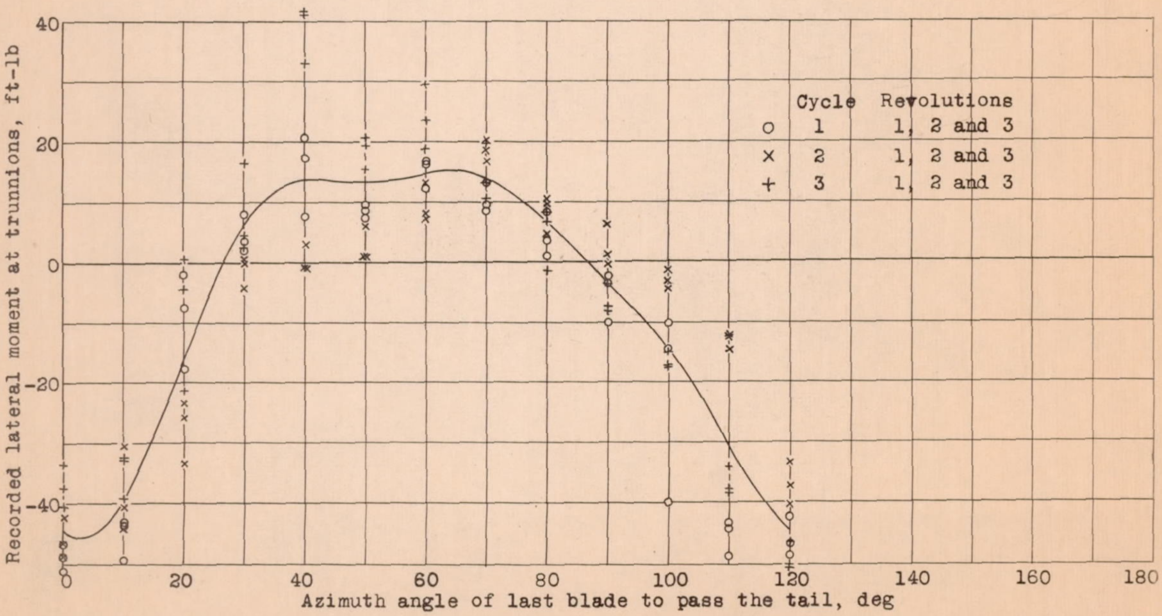


Figure 5,- Variation of recorded lateral moment at the trunnions with azimuth angle of the last rotor blade to pass over the tail. $\mu = 0.325$. YG - 1B autogiro.

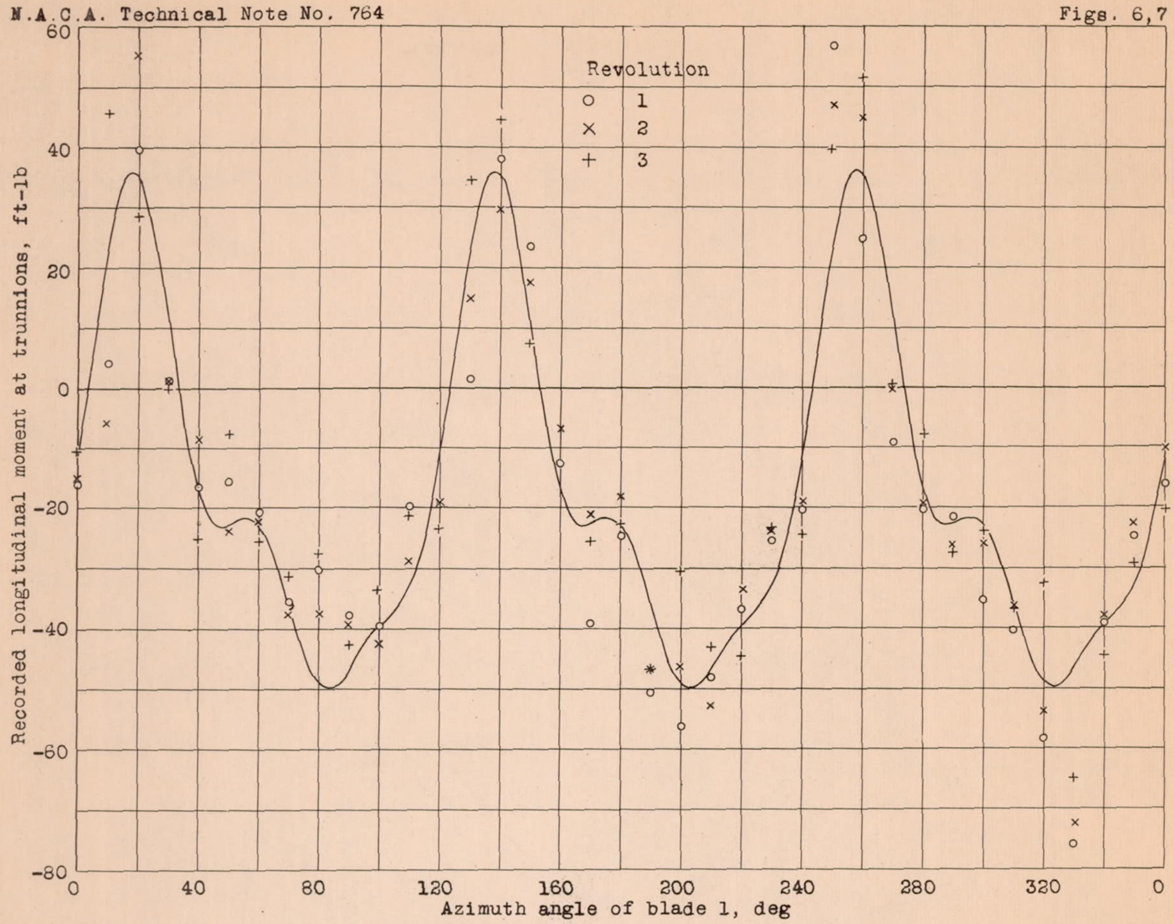


Figure 6.- Variation of recorded longitudinal moment at the trunnions with azimuth angle of blade 1. $\mu = 0.325$. YG-1B autogiro.

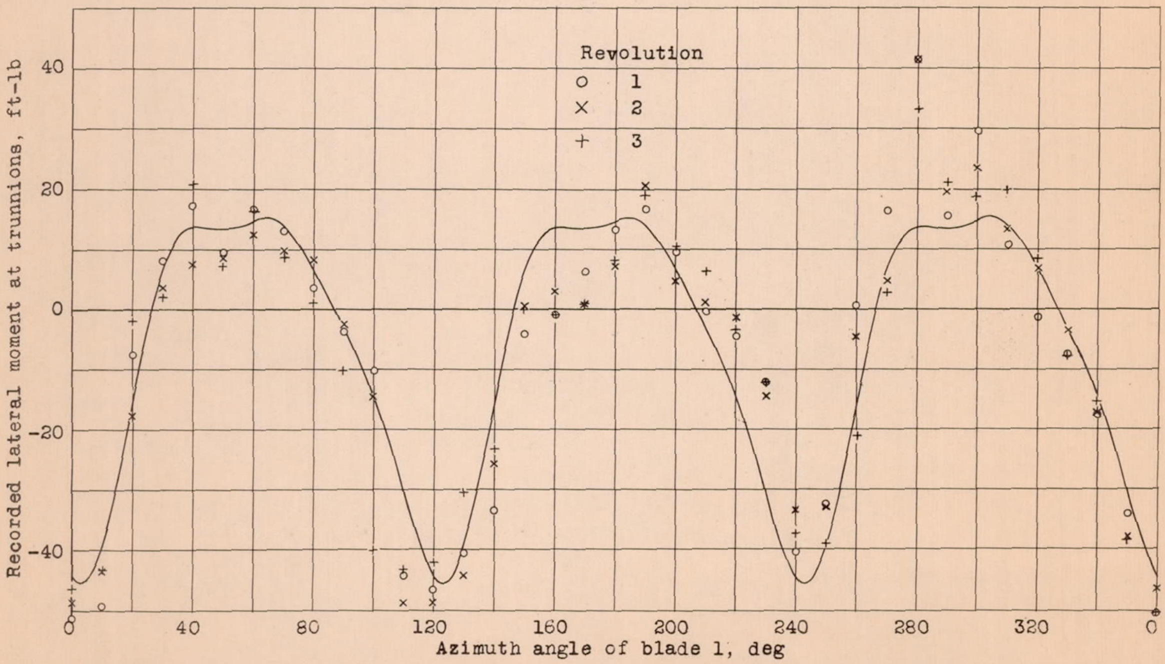


Figure 7.- Variation of recorded lateral moment at the trunnions with azimuth angle of blade 1. $\mu = 0.325$. YG-1B autogiro.

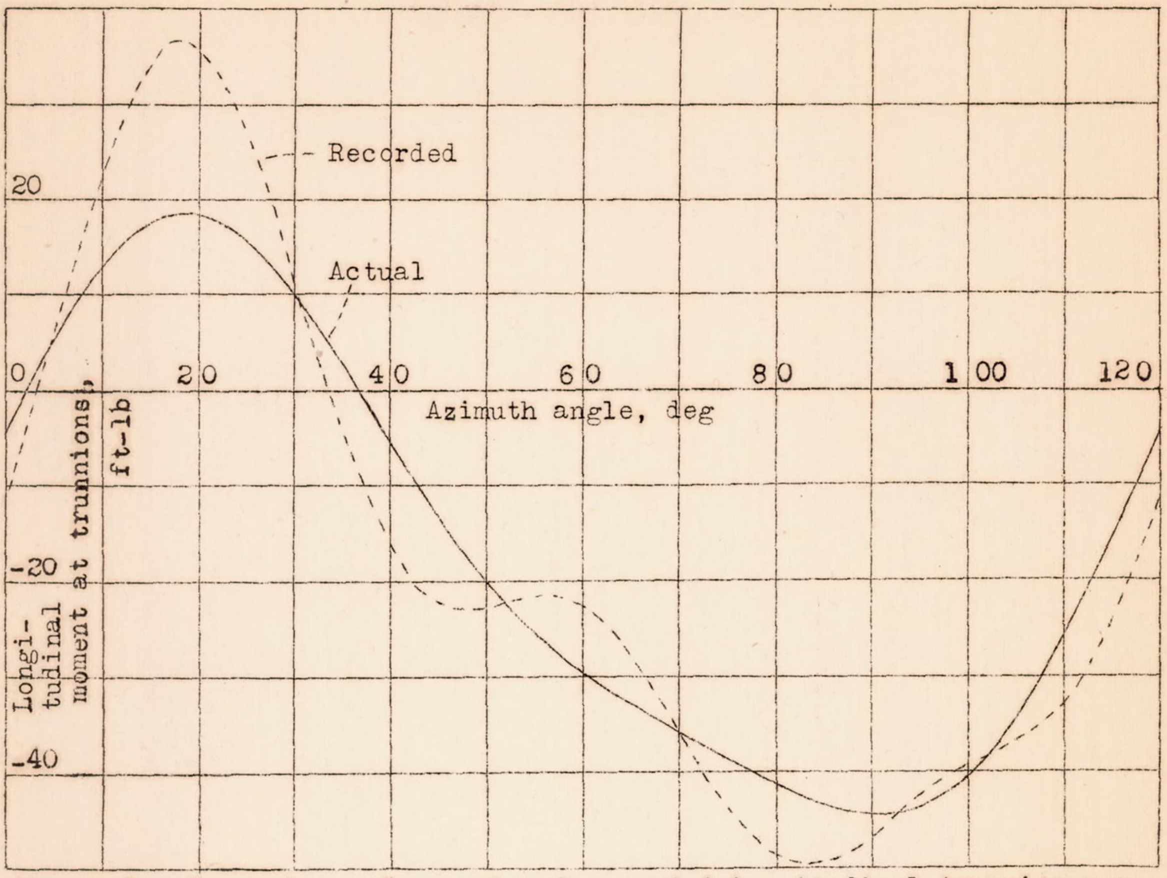


Figure 8.- Comparison of actual and recorded longitudinal trunnion moments. μ = 0.325. YG-1B autogiro.

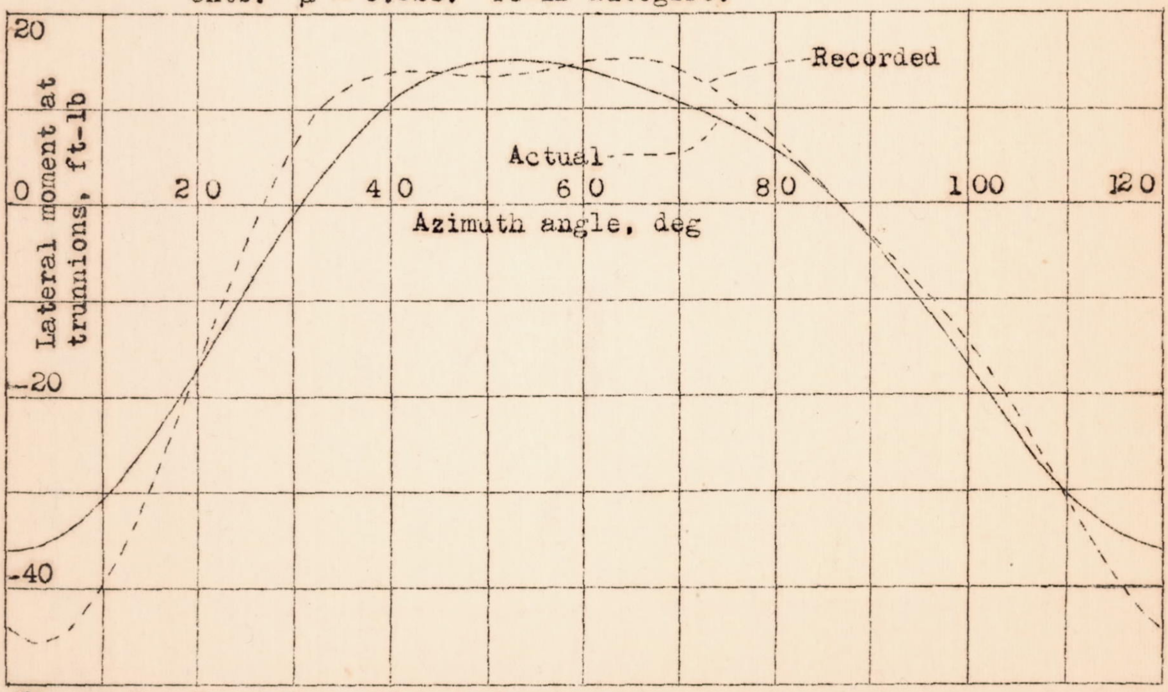


Figure 9.- Comparison of actual and recorded lateral trunnion moments. μ = 0.325. YG-1B autogiro.

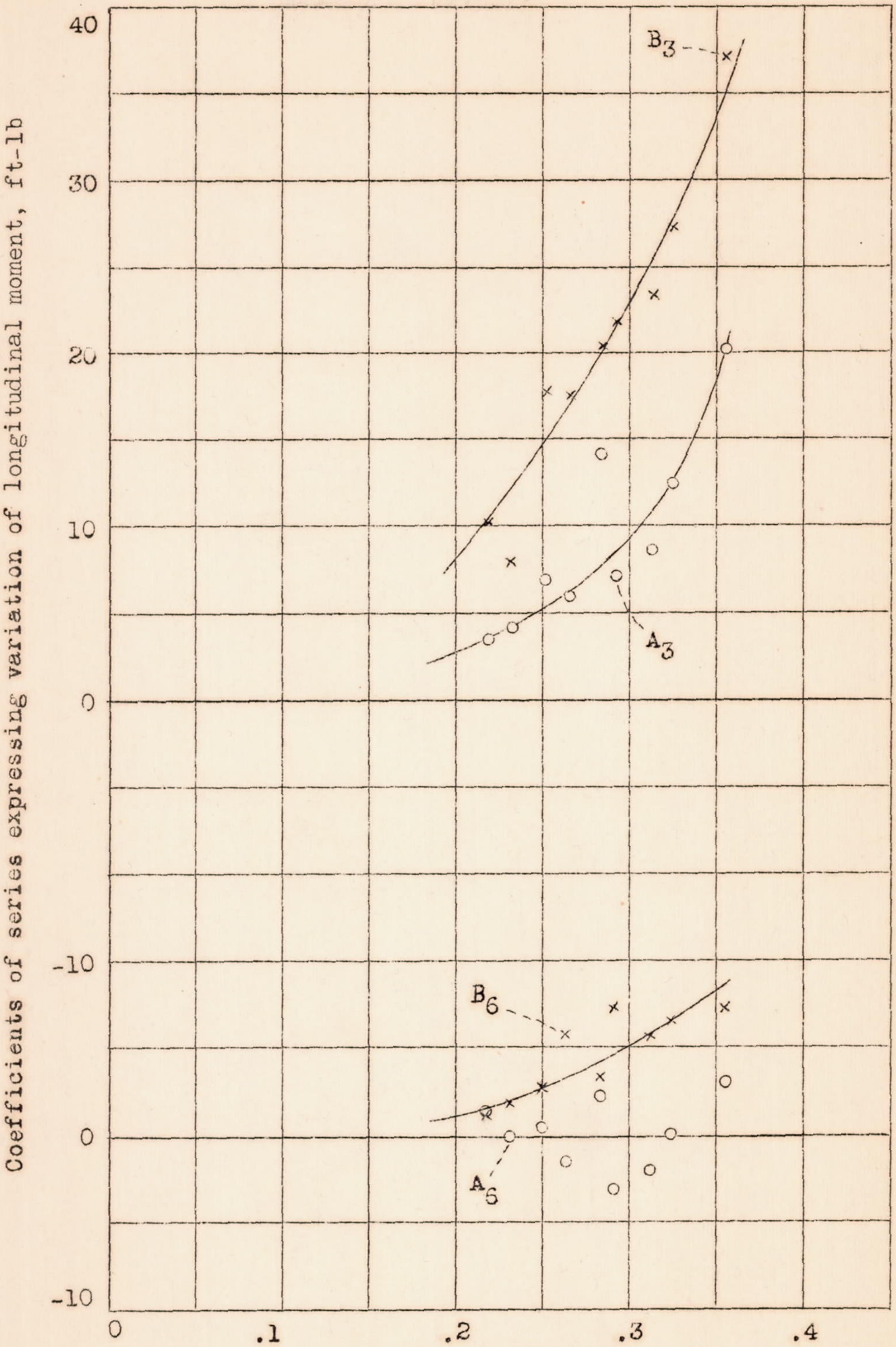


Figure 10.- Periodic variation of longitudinal trunnion moment as a function of tip-speed ratio. YG-1B autogiro.

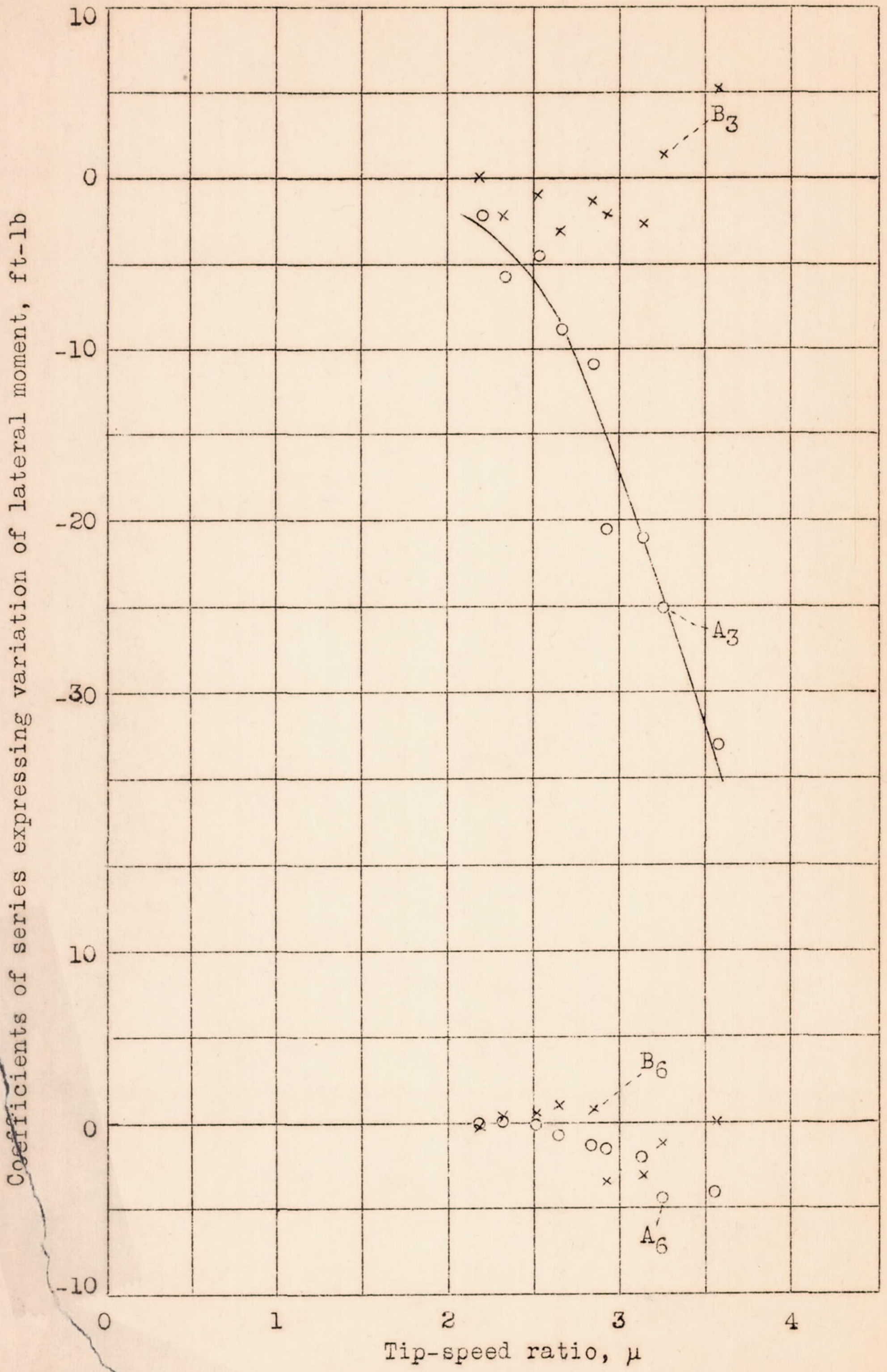


Figure 11.- Periodic variation of lateral trunnion moment as a function of tip-speed ratio. YG-1B autogiro.